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Air Pollution, Lung Function, and Physical Symptoms in Communities Near Concentrated Swine Feeding Operations

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Abstract

Background—Concentrated animal feeding operations emit air pollutants that may affect health. We examined associations of reported hog odor and of monitored air pollutants with physical symptoms and lung function in people living within 1.5 miles of hog operations.

Methods—Between September 2003 and September 2005, we measured hydrogen sulfide (H_2S), endotoxin, and particulate matter (PM_{10}, $PM_{2.5}$, and $PM_{2.5–10}$) for approximately 2-week periods in each of 16 eastern North Carolina communities. During the same time periods, 101 adults sat outside their homes twice a day for 10 minutes, reported hog odor and physical symptoms, and measured their lung function. Conditional fixed-effects logistic and linear regression models were used to derive estimates of associations.

Results—The log odds (±1 standard error) of acute eye irritation following 10 minutes outdoors increased by 0.53 (±0.06) for every unit increase in odor, by 0.15 (±0.06) per 1 ppb of H_2S, and by 0.36 (±0.11) per 10 μg/m^3 of PM_{10}. Odor and H_2S were also associated with irritation and respiratory symptoms in the previous 12 hours. The log odds of difficulty breathing increased by 0.50 (±0.15) per unit of odor. A 10 μg/m^3 increase in mean 12-hour $PM_{2.5}$ was associated with increased log odds of wheezing (0.84 ± 0.29) and declines in forced expiratory volume in 1 second (−0.04 ± 0.02 L). A 10 EU/mg increase in endotoxin was associated with increased log odds of sore throat (0.10 ± 0.05), chest tightness (0.09 ± 0.04), and nausea (0.10 ± 0.05).

Conclusions—Pollutants measured near hog operations are related to acute physical symptoms in a longitudinal study using analyses that preclude confounding by time-invariant characteristics of individuals.

Concentrated animal feeding operations contribute to local, regional, and global air pollution.[1] Pollutants of local importance include odor,[2,3] hydrogen sulfide (H_2S),[4] endotoxin,[5] particulate matter (PM),[6,7] and ammonia (NH_3).[8,9]

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Several cross-sectional studies have examined the health of people living near concentrated hog operations on the basis of residential proximity to classify exposure. In a population-based survey, neighbors of hog operations reported more episodes of headache, runny nose, sore throat, coughing, diarrhea, and burning eyes compared with demo-graphically similar persons who did not live near a hog operation.[10] Among children, indicators of asthma have been related to measures of residential[11] and school[12,13] exposures to pollution from hog operations. In an area of Germany with a high density of concentrated animal feeding operations, reported odor annoyance was associated with prevalence of wheeze without a cold, and physician-diagnosed asthma and allergic rhinitis. Additionally, the number of operations within 500 meters of participants' homes was associated with increased odds of wheezing without a cold, and with diminished lung function.[14] These symptoms overlap with conditions reported in studies of occupational exposures of animal-confinement-house workers, including decreased lung function,[15–17] chronic cough,[17] excess phlegm production, chest tightness,[18] scratchy throat, eyes and mucous membrane irritation, shortness of breath,[16] and wheezing.[18]

Community Health Effects of Industrial Hog Operations was a longitudinal, community-driven, participatory study of air pollution, health, and quality of life among persons living near hog operations. We have previously described associations between air pollution and hog odor,[19] air pollution and measures of stress and negative mood,[20] and factors associated with data quality and completeness.[21] Here we report relationships between measures of air pollution, symptoms, and lung function, focusing on physical symptoms that have been of interest in cross-sectional studies.[22]

Methods

Between September 2003 and September 2005, residents of 16 eastern North Carolina communities collected health data for approximately 2 weeks while pollutant concentrations were monitored continuously. Communities participated sequentially using the same set of air-monitoring devices.

Nonsmoking volunteers aged at least 18 years residing within 1.5 miles of at least one hog operation were recruited through community-based organizations. The lead community organization for this study was the Concerned Citizens of Tillery.[23] Participants attended a 3-hour training session at which they gave informed consent and practiced completing all data-collection activities. The study design has been described in detail elsewhere.[23]

The Institutional Review Board of the University of North Carolina at Chapel Hill reviewed and approved study activities annually.

Exposure Variables

Odor—Participants spent 10 minutes outdoors at preselected morning and evening times approximately 12 hours apart. While outside, they rated, on a scale of 0 (none) to 8 (very strong), the strength of the hog odor they recalled having smelled during each of the 12 preceding hours. Participants then returned indoors and rated hog odor present during the 10 minutes outside on the same 9-point scale.

We analyzed 2 hog odor variables. Twelve-hour mean odor is the average of the hourly odor levels reported for each of the 12 hours before the morning or evening data collection time. Twice-daily odor is the odor during the 10 minutes outdoors.

Air Monitoring—Continuous air pollution monitors, mounted on a trailer that was centrally located in each community, recorded concentrations of hydrogen sulfide (H_2S), semi-volatile particulate matter less than 10 micrometers in diameter (semivolatile PM_{10}), particulate matter less than 10 micrometers in diameter that excluded the volatile fraction (PM_{10}), coarse PM ($PM_{2.5–10}$), fine PM ($PM_{2.5}$), and endotoxin. An MDA Scientific Single Point Monitor (Honeywell Analytics Inc North America, Lincolnshire, IL) recorded H_2S concentrations every 15 minutes in parts per billion (ppb). Hourly concentrations of PM_{10} and semivolatile PM_{10} were measured in micrograms per cubic meter ($\mu g/m^3$), using a Tapered Element Oscillating Microbalance Series 1400a Ambient Particulate Monitor with a Series 8500 Filter Dynamics Measurement System (Thermo Fisher Scientific, Waltham, MA). In the first 12 of 16 communities, a Dichotomous Partisol-Plus 2025-D Sequential Air Sampler (Thermo Fisher Scientific, Waltham, MA) was used to collect 12-hour samples of $PM_{2.5–10}$ and $PM_{2.5}$ ($\mu g/m^3$) on filters that were assayed for endotoxin in endotoxin units per milligram (EU/mg). Endotoxin levels from $PM_{2.5–10}$ filters were quantified by kinetic chromogenic Limulus amebocyte lysate assay[24,25]; $PM_{2.5–10}$ filters contained approximately 60% of the endotoxin in the PM_{10}.

We calculated the mean concentrations of H_2S, PM_{10}, and semivolatile PM_{10} in the 1- and 12-hour periods that preceded the time at which participants sat outdoors for 10 minutes. Concentrations of $PM_{2.5}$, $PM_{2.5–10}$, and endotoxin were measured on 12-hour filters that typically did not correspond to exposure periods of interest. Thus, we estimated these exposures with a time-weighted average of the concentrations from filters exposed during the 12 hours prior to sitting outdoors. All exposure variables were coded continuously.

Outcome Variables—Given the short follow-up and focus on transient exposures, we analyzed symptoms that could appear and resolve during follow-up.

Physical Symptoms—After sitting outside their homes for 10 minutes and then returning inside, participants noted whether they experienced cough or irritation of the skin, eyes, nose, or throat while outside (Table 1). Symptoms of acute irritation, reported as present or absent, were analyzed in relation to odor levels reported for the same 10 minutes and in relation to averages of PM and H_2S in the hour prior to the time participants returned indoors. After returning indoors, participants rated the extent to which they experienced any of 19 acute physical symptoms in the preceding 12 hours on a scale of 0 (not at all) to 8 (extreme).

We considered the following 12-hour symptoms: respiratory (runny nose, mucus or phlegm, sore throat, cough, wheezing, difficulty breathing, chest tightness), irritation (burning eyes, itching eyes, nasal), gastrointestinal (nausea, diarrhea, poor appetite), neurologic (headache, dizziness), and other (aching joints, difficulty hearing, fever, and backache). Reports of most physical symptoms were uncommon, so we dichotomized them as absent versus present based on the distribution of responses for each symptom such that at least 85% of responses

were coded as 0 and no more than 15% were coded as 1. Runny nose, mucus or phlegm, headache, cough, burning eyes, aching joints, nasal irritation, and itching eyes were dichotomized such that a response of 0 or 1 on the original scale was coded as 0 and a response of 2–8 was coded as 1. For the remaining symptoms, a response of 0 on the original scale was coded as 0 and 1–8 was coded as 1.

Lung Function—Participants used an AirWatch personal respiratory monitor (iMetrikus, Inc., Sunnyvale, CA) to measure forced expiratory volume in the first second (FEV_1) and peak expiratory flow rate (PEF) during each data collection session. The AirWatch internally recorded each of 3 attempts and flagged any that were made with problematic technique. The highest error-free FEV_1 and PEF measurements from each session (sometimes there were none) were included in the analysis as continuous outcome variables.

Statistical Analyses

In this longitudinal study of transient exposures and outcomes, each participant served as her or his own control. The analytic goal was to make valid within-participant comparisons to determine whether increases in air pollutant concentrations or odor ratings were associated with physical symptoms and lung function. Estimates of associations were constructed using conditional fixed-effects linear and logistic regression models. In these models, the within-person correlation due to repeated measures is accounted for by treating each person as a stratum within the model.[26] This approach has good control of measured and unmeasured time-invariant individual level confounders. These models account for the longitudinal nature of the data by modeling differences between individuals' time-specific characteristics and their mean value over the entire period of follow-up.

Time of day was integral to the study design because community members collected data at morning and evening times that were approximately 12 hours apart. Physical symptoms, lung function, and hog odors exhibit diurnal variation,[19] and thus we made an a priori decision to adjust for potential confounding due to time of day by including a term for morning versus evening in all models. There was little variance in community effects; therefore we did not include the community level in our models.

Because of the large number of exposure and outcome variables, we did not restrict analyses to participant records with complete data for all variables. Each analysis excludes only those observations that were missing data for the exposure and outcome being analyzed.

Results

There was a median of 9 hog operations within 2 miles of participating communities, and the median number of hogs within that radius was approximately 42,000 (Table 1). Study participants ranged in age from 19 to 90; their mean age was 53. Over half of participants were women, and most participants described themselves as black. Overall, the study population was healthy, with zero participants reporting emphysema and 12 reporting asthma or chronic bronchitis (Table 1). The participants provided 2949 journal entries. There were approximately 2600 responses about irritation symptoms following the 10-minutes outdoors, 2900 responses about physical symptoms experienced in the last 12 hours, and

1900 error-free measurements of lung function (eAppendix 1, http://links.lww.com/EDE/A453).

Average ambient air pollutant values are presented in eAppendix 2 (http://links.lww.com/EDE/A453). There were approximately 2700 values of H_2S and 2000 values of semi-volatile PM_{10} and PM_{10}; the smaller numbers of observations for the latter 2 pollutants were due to equipment malfunction in hot and humid weather. There were approximately 1750 values for $PM_{2.5–10}$, $PM_{2.5}$, and endotoxin in the 12 communities where these pollutants were measured. Overall means, minimum and maximum community means, and between-community variation (as a % of total) are reported in eAppendix 2 (http://links.lww.com/EDE/A453). Two negative minimum community means for semivolatile PM_{10} occurred due to measurement error in the microbalance estimates of mass close to zero. More than half of the total variation in air pollutant measurements occurred between communities for 12-hour odor and 12-hour semivolatile PM_{10}. For the other measured pollutants, the majority of the variation occurred within the communities over time. This was particularly true for 1-hour and 12-hour H_2S and 1-hour and 12-hour PM_{10}, for which the between-community variances were approximately 4%, 6%, 6%, and 15%, respectively.

Associations of acute irritation symptoms with twice-daily (10-minute) odor reports and 1-hour average pollution levels are presented in Table 2. Irritation symptoms were elevated in association with odor and H_2S, and most coefficients were substantially greater than their standard errors. Estimates of associations between 1-hour PM_{10} and irritation symptoms were near zero for nasal and throat irritation, and cough, whereas associations were positive for eye and skin irritation. Coefficients for semivolatile PM_{10} were both positive and negative and similar in magnitude or smaller than their standard errors.

Estimates of associations of 12-hour average odor, H_2S, PM_{10}, and semivolatile PM_{10} with lung function measures and 12-hour symptom variables are presented in Table 3. Point estimates for PEF and FEV_1 are negative except for the coefficient for PM_{10} and PEF. *T* values indicate that the negative coefficients are less than or equal in value to their standard errors, the largest being for the association between odor and FEV_1.

Point estimates of associations of respiratory symptoms with odor and H_2S were positive except for the coefficient between H_2S and chest tightness (Table 3). The log odds of having experienced 4 of the 7 respiratory symptoms were positive for PM_{10} and semivolatile PM_{10}. However, most of these estimates were close to zero, with the exception of difficulty breathing and 12-hour mean semivolatile PM_{10}. Additionally, sore throat symptom reports were negatively associated with increases in PM_{10}.

We observed positive associations (with high χ^2 values) of irritation symptoms in the past 12 hours with 12-hour mean odor and with 12-hour mean H_2S (Table 3). Twelve-hour irritation symptoms were not associated with 12-hour mean PM_{10} or semivolatile PM_{10} (Table 3). Overall, we found little association between gastrointestinal symptoms and 12-hour mean odor, H_2S, PM_{10}, or semivolatile PM_{10}, with the exception of a positive association between PM_{10} and poor appetite. We found little evidence of associations between neurologic symptoms and 12-hour mean odor, H_2S, PM_{10}, or semivolatile PM_{10}.

Point estimates for the symptoms in the "other" category varied in magnitude and direction. Eleven of the 16 point estimates were negative, although most had very small χ^2 values. The highest χ^2 values were for the relationships of aching joints and difficulty hearing with 12-hour mean semivolatile PM_{10}, although the estimates were in opposite directions (−0.93 ± 0.47 and 1.78 ± 0.65, respectively).

Twelve-hour average concentrations of $PM_{2.5–10}$, $PM_{2.5}$, and endotoxin were modeled as predictors of lung function and 12-hour symptoms in the 12 communities with results from the sequential air sampler (n = 70 participants, Table 4). *T* values for beta coefficients from linear conditional fixed effects models were small except for the association between $PM_{2.5}$ and FEV_1 FEV_1 decreased 0.04 ± 0.02 L per 10 μtg/m^3 increase in 12 hour mean $PM_{2.5}$.

Associations between symptoms and pollutants measured by the sequential sampler in the 12 communities with these measurements are also presented in Table 4. Most χ^2 values were small, indicating that these exposure measures were poor predictors of symptoms. High χ^2 values were observed for associations between $PM_{2.5–10}$ and 3 symptoms, $PM_{2.5}$ and 5 symptoms, and endotoxin and 3 symptoms. $PM_{2.5–10}$ was negatively associated with chest tightness and nausea and positively associated with aching joints. Symptoms showed more consistently positive associations with $PM_{2.5}$ (wheezing, difficulty breathing, burning eyes, nasal irritation, backache) and endotoxin (sore throat, chest tightness, nausea).

The models reported in Tables 2–4 were also fit using random effects mixed models and produced very similar results.

Discussion

Concerns about air pollution from animal production facilities have grown with the global industrialization of food animal production.[1,10–14,27,28] Concentrated hog feeding operations release air pollutants from confinement buildings, manure holding pits, and land-application of animal wastes.[1,29,30] Although cross-sectional studies have documented relationships of proximity to hog operations with physical symptoms[10–14,31,32] and with reduced FEV_1,[14] they have lacked air pollution measures and most have depended solely on participant recall of symptoms over time periods of 6–12 months. The present study contributes to the literature by linking twice-daily symptom reports and lung function measurements of people residing near hog operations with physical measures of ambient air pollutant concentrations.

Several limitations should be considered in interpreting the results of this study. First, although we have repeated measures for each participant, the number of people in the study is small. The small sample size contributes to imprecision of measures of association and also limits our ability to quantify variability in measures of association between subgroups.

Several factors may limit the external validity of the study findings. The 16 study communities are not a random sample of eastern North Carolina, and we are not able to evaluate the extent to which the characteristics of air pollutants or the volunteers in the study are representative of other populations living near industrial hog operations. Furthermore, participants were nonsmoking volunteers, mostly free of chronic respiratory diseases. Associations between hog operation pollutants and health outcomes may be different among

smokers and people with asthma or other conditions that increase responsiveness to pollutants. About three-fourths of the study participants reported growing up around livestock, which has been associated with lower levels of atopy in some studies.[33–35] We did not measure atopy; however, 43% of participants who grew up on a farm reported hay fever compared with 19% of those who did not, suggesting that early exposure to livestock may not have resulted in reduced responsiveness to pollutants in this population.

The air-monitoring equipment for this study was large and difficult to conceal. In some communities, participants reported reductions in hog odor and spraying of hog waste during the study compared with time periods before and after the equipment was in their neighborhoods. Changes in waste management practices could have lowered exposure levels during the study, and consequently our ability to detect effects. In addition, exposure variability within communities could not be quantified by the stationary, centrally located monitors.

Finally, lung function data were of lower quality and were less complete than other outcome data.[21] Lung function assessment depends upon proper technique and is ideally conducted by a laboratory technician.[36] In this study, participants were trained to make 3 measurements to the best of their ability each time they collected data. Given the community-based setting, we did not feel it was appropriate to apply American Thoracic Society/European Respiratory Society standards to these measurements.[37] Instead, we analyzed only error-free readings, further reducing sample size and the precision of estimates of association. Therefore, it is of interest that a 10 μg/m^3 increase in $PM_{2.5}$ (measured only in 12 of the 16 communities) was associated with a 0.04 ± 0.02 L decrease in FEV_1 ($T = -2.12$).

Despite these limitations, most exposure-outcome relationships were in the predicted direction; most of those not in the predicted direction were weak. We observed unexpected negative associations between PM_{10} and sore throat, $PM_{2.5–10}$ and nausea and chest tightness, and semi volatile PM_{10} and aching joints. We are not aware of any biologic mechanisms whereby these air pollutants or unmeasured copollutants could protect against development of these symptoms. Although the study design and analytic methods preclude confounding by time-invariant characteristics of participants, these negative associations could reflect uncontrolled time-related confounding, measurement error, or both.

In addition, our findings were generally consistent with prior studies of airborne emissions from industrial hog operations. For example, in a controlled experiment, 48 healthy adult volunteers (mean age = 26) reported eye irritation and nausea more frequently when exposed to diluted swine air than when exposed to clean air.[38] Radon et al[14] found evidence of decreased FEV_1 and increased wheezing in association with the number of concentrated animal feeding operations near participants' residences, and increased reports of asthma and nasal allergies in association with reported annoyance with odor. Mirabelli et al[12] observed a 23% higher prevalence of wheezing among children who attended schools where staff reported livestock odor inside school buildings twice or more per month, compared with schools where no livestock odor was reported. In a cross-sectional study of rural Iowa children, living on a farm that raised swine and added antibiotics to animal feed was associated with asthma-related outcomes.[11] Finally, endotoxin exposures have been

associated with increased respiratory and systemic symptoms and decreased lung function,[39] and working in hog operations has also been associated with respiratory symptoms, reduced lung function, and organic dust toxic syndrome.[15,16,40,41]

Interestingly, in contrast to some other studies, we did not observe an association between hog operation air pollutants and headaches.[10,38,42] It is possible that headaches are more prevalent among individuals living near hog operations, but that the incidence of headaches does not covary with odor and pollutants on the short-time scale used in our study. Although an acute association with headache was observed in a chamber study,[38] that exposure was diluted air from a swine confinement building, and the experimental subjects were naive volunteers who did not live near hog operations.

Among the pollutants we measured, H_2S (which is produced by anaerobic decomposition of sulfur-containing organic matter in hog waste pits[1]) provides a fairly specific measure of hog operation pollution in these rural areas where there are few other industrial sources of H_2S. In contrast to H_2S, PM is a ubiquitous air pollutant with many sources and has been previously associated with lower lung function, heart rate variability, and mortality.[43–46] In addition to solid particle sources, constituents of PM may form indirectly in the atmosphere through reactions of precursor gases such as NH_3[47] to form soluble substances such as ammonium nitrate.[48] These particles may be semivolatile, in equilibrium between gas and particle phases,[49] and may have different effects than nonvolatile fractions of PM. Therefore observed associations between PM, symptoms, and lung function could be due to PM emitted by hog operations, PM from other sources, or both. We were specifically interested in $PM_{2.5–10}$ because of the possibility that hog dander, feed, dried feces, endotoxin, and other microbial matter would be present in the coarse fraction.[30] However, of all the pollution measures, $PM_{2.5–10}$ showed the smallest and least precise associations with symptoms and lung function.

Conclusions

This longitudinal study contributes to evidence obtained from cross-sectional research that suggests that air pollutants near hog operations cause acute physical symptoms, particularly upper respiratory symptoms and irritation of the nose and eyes. Despite limitations of measurements of exposure and outcome, the temporal nature of the analysis eliminates confounding from time-invariant factors and strengthens the evidence. Adjustment for time of day helps reduce any time-related confounding that could be introduced by diurnal covariation in symptoms and air pollutants. Variability in pollutants within morning and evening periods is large enough so that overadjustment is not a concern.

Industrial hog operations in North Carolina are disproportionately located in low-income communities of color[10,29] where there is more potential for exposure to outdoor air pollutants due to older homes that are not air tight and have no air conditioning. Many residents also lack the financial resources to travel and choose activities that could help them avoid high pollution. Exposure to air pollution from hog operations is an environmental injustice in rural areas hosting facilities that supply pork to populations spared the burdens of its production.

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Table 1
Characteristics of Communities (n = 16) and Study Participants (n = 101)

Characteristic	No.
Concentrated swine feeding operations within 2 miles of community	
Median	9
Range	1–16
Permitted no. hogs (in thousands) within 2 miles of community	
Median	42
Range	4–77
Diary entries per participant	
Median	28
Range[a]	7–6
Race and sex	
Black women	57
Black men	28
Nonblack women	9
Nonblack men	7
Exposed to passive smoking[b]	5
Chronic respiratory disease[c]	
Emphysema[d]	0
Asthma[e]	5
Chronic bronchitis[f]	3
Asthma and chronic bronchitis	4
Hay fever allergy[f]	34
Dust, animal, or food allergy[d]	30
Grew up around livestock[g]	76

[a] Some participated for more than 2 weeks.

[b] Eligible participants were nonsmokers.

[c] Based on participant report of diagnosis by a physician at any point in his or her life.

[d] Number missing = 9.

[e] Number missing = 10.

[f] Number missing = 8.

[g] Number missing = 3.

Table 2

Logistic Fixed Effects Models of Hog Odor, Hydrogen Sulfide, Nonvolatile PM_{10}, and Semivolatile PM_{10} as Predictors of Acute Irritation Symptoms Reported Immediately After Participants Spent 10 Minutes Outdoors[a]

	Twice-daily Odor			1-h Average H_2S per 1 ppb			1-h Average PM_{10} per 10 μg/m^3			1-h Average Semivolatile PM_{10} per 10 μg/m^3		
	β	SE	χ^2	β	SE	χ_2	β	SE	χ^2	β	SE	χ^2
Eye irritation	0.53	0.06	87.49	0.15	0.06	6.10	0.36	0.11	10.12	0.16	0.27	0.37
Nasal irritation	0.65	0.05	151.68	0.08	0.03	6.83	−0.00	0.04	0.00	−0.11	0.22	0.23
Throat irritation	0.41	0.06	41.75	0.12	0.07	2.49	−0.03	0.05	0.33	0.26	0.33	0.65
Skin irritation	0.37	0.16	5.56	0.13	0.25	0.26	0.56	0.38	2.17	0.47	0.93	0.26
Cough	0.25	0.07	11.89	0.14	0.12	1.34	−0.02	0.11	0.05	−0.48	0.41	1.32

[a] All models are adjusted for time of day (AM/PM).

SE indicates standard error; PM, particulate matter.

Table 3

Linear and Logistic Fixed Effects Models of 12-hour Average Hog Odor, Hydrogen Sulfide, Nonvolatile PM_{10}, and Semivolatile PM_{10} as Predictors of Lung Function and 12-hour Symptoms[a]

	12-h Average Odor			12-h Average H_2S per 1 ppb			12-h Average PM_{10} per 10 μg/m^3			12-h Average Semivolatile PM_{10} per$_{10}$ μg/m^3		
Lung Function												
Linear Models	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***
PEF	−0.52	(1.58)	−0.33	−0.46	(0.71)	−0.65	1.29	(1.17)	1.10	−7.39	(4.87)	−1.52
FEV_1	−0.02	(0.01)	−1.67	−0.01	(0.01)	−1.43	-0.00	(0.00)	−0.22	−0.04	(0.04)	−1.04
Symptoms												
Logistic Models	***β***	**SE**	χ^2	***β***	**SE**	χ^2	***β***	**SE**	χ^2	***β***	**SE**	χ^2
Respiratory												
Runny nose	0.27	(0.10)	7.29	0.29	(0.09)	10.00	−0.10	(0.10)	1.00	0.35	(0.37)	0.91
Mucus or phlegm	0.19	(0.14)	1.91	0.07	(0.09)	0.65	−0.22	(0.13)	2.67	−0.44	(0.47)	0.90
Sore throat	0.08	(0.11)	0.56	0.03	(0.04)	0.39	−0.25	(0.13)	3.54	−0.24	(0.40)	0.38
Cough	0.36	(0.15)	5.50	0.09	(0.10)	0.80	0.02	(0.10)	0.02	−0.45	(0.45)	1.01
Wheezing	0.18	(0.16)	1.36	0.09	(0.06)	2.40	0.16	(0.11)	2.33	0.20	(0.56)	0.13
Difficulty breathing	0.50	(0.15)	11.18	0.33	(0.13)	7.06	0.05	(0.08)	0.50	1.22	(0.39)	9.99
Chest tightness	0.12	(0.12)	1.11	−0.01	(0.09)	0.02	0.01	(0.09)	0.02	0.53	(0.37)	1.99
Irritation												
Burning eyes	0.32	(0.10)	10.12	0.19	(0.07)	6.29	0.01	(0.09)	0.03	0.10	(0.43)	0.06
Itching eyes	0.17	(0.10)	2.71	0.12	(0.05)	5.15	0.05	(0.10)	0.26	0.01	(0.44)	0.00
Nasal irritation	0.46	(0.13)	13.67	0.12	(0.04)	7.90	0.00	(0.07)	0.00	−0.17	(0.39)	0.20
Gastrointestinal												
Nausea	0.21	(0.17)	1.59	0.18	(0.13)	1.82	−0.08	(0.17)	0.22	0.02	(0.59)	0.00
Diarrhea	−0 10	(0 28)	0 14	−0.05	(0.24)	0.04	−0.27	(0.30)	0.81	−0.46	(0.83)	0.30
Poor appetite	−0.03	(0.29)	0.01	−0.25	(0.34)	0.54	0.51	(0.20)	6.24	−0.05	(0.61)	0.01
Neurological												
Headache	0.12	(0.12)	1.00	−0.07	(0.09)	0.60	−0.03	(0.11)	0.09	0.32	(0.32)	0.96
Dizziness	0.11	(0.10)	1.25	0.06	(0.07)	0.88	0.15	(0.11)	1.92	−0.14	(0.34)	0.17

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	12-h Average Odor			12-h Average H_2S per 1 ppb			12-h Average PM_{10} per 10 μg/m^3			12-h Average Semivolatile PM_{10} per$_{10}$ μg/m^3		
	Lung Function											
Linear Models	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***
Other												
Aching joints	−0.01	(0.13)	0.01	−0.05	(0.13)	0.14	0.09	(0.07)	1.60	−0.93	(0-47)	3.84
Difficulty hearing	−0.16	(0.23)	0.51	−0.91	(0.64)	2.03	0.17	(0.11)	2.62	1.78	(0.65)	7.47
Fever	−0.02	(0.53)	0.00	0.65	(0.41)	2.48	−0.07	(0.38)	0.03	−3.32	(1.91)	3.04
Backache	−0.16	(0.14)	1.25	−0.04	(0.09)	0.17	0.13	(0.07)	3.03	−0.23	(0.39)	0.35

[a] All models are adjusted for time of day (am/pm).

SE indicates standard error; PEF, peak expiratory flow; FEV_1, forced expiratory volume in the first second; PM, particulate matter.

Table 4

Linear and Logistic Fixed Effects Models of Coarse Particles, Fine Particles, and Endotoxin as Predictors of Lung Function and Symptoms[a]

	12-h$PM_{2.5–10}$ per 10 μg/m^3			12-h $PM_{2.5}$ per 10 μg/m^3			12-h Endotoxin per 10 EU/mg		
Lung Function									
Linear Models	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***
PEF	1.96	(2.08)	0.94	−0.19	(2.64)	−0.07	0.23	(0.45)	0.53
FEV_1	0.01	(0.02)	0.52	−0.04	(0.02)	−2.12	0.00	(0.00)	0.37
Symptoms									
Logistic Models	**β**	**SE**	**χ^2**	**β**	**SE**	**χ^2**	**β**	**SE**	**χ^2**
Respiratory									
Runny nose	−0.16	(0-24)	0.46	0.13	(0.20)	0.39	0.02	(0.04)	0.41
Mucus or phlegm	−0.02	(0.15)	0.02	−0.18	(0.28)	0.40	−0.01	(0.05)	0.08
Sore throat	−0.50	(0.52)	0.91	−0.30	(0.25)	1.45	0.10	(0.05)	3.46
Cough	−0.70	(0.51)	1.89	0.01	(0.29)	0.00	0.03	(0.05)	0.33
Wheezing	0.19	(0.26)	0.55	0.84	(0.29)	8.64	−0.01	(0.06)	0.02
Difficulty breathing	−0.62	(0.42)	2.17	0.50	(0.24)	4.37	0.06	(0.05)	1.47
Chest tightness	−0.84	(0.45)	3.56	0.02	(0.24)	0.00	0.09	(0.04)	6.42
Irritation									
Burning eyes	0.15	(0.20)	0.55	0.61	(0.22)	7.78	0.02	(0.04)	0.25
Itching eyes	−0.08	(0.18)	0.21	0.38	(0.24)	2.53	0.03	(0.04)	0.72
Nasal irritation	−0.03	(0.14)	0.07	0.48	(0.25)	3.66	0.00	(0.04)	0.01
Gastrointestinal									
Nausea	−1.43	(0.71)	4.06	−0.09	(0.32)	0.07	0.10	(0.05)	3.64
Diarrhea	−1.11	(1.21)	0.85	−0.07	(0.45)	0.02	0.04	(0.10)	0.12
Poor appetite	0.62	(0.90)	0.47	−0.25	(0.62)	0.16	−0.03	(0.10)	0.08
Neurological									
Headache	−0.31	(0.39)	0.61	−0.18	(0.22)	0.63	0.06	(0.05)	1.74
Dizziness	−0.54	(0.46)	1.40	−0.26	(0.23)	1.29	0.04	(0.05)	0.77
Other									

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	12-h $PM_{2.5-10}$ per 10 $\mu g/m^3$			12-h $PM_{2.5}$ per 10 $\mu g/m^3$			12-h Endotoxin per 10 EU/mg		
Lung Function									
Linear Models	***β***	**SE**	***t***	***β***	**SE**	***t***	***β***	**SE**	***t***
Aching joints	0.30	(0.15)	3.99	0.02	(0.24)	0.01	0.00	(0.04)	0.01
Difficulty hearing	−0.10	(0.43)	0.05	0.53	(0.41)	1.70	0.04	(0.07)	0.41
Fever	0.18	(0.95)	0.04	−0.64	(0.79)	0.67	0.19	(0.14)	1.96
Backache	−0.02	(0.15)	0.01	0.61	(0.25)	5.86	0.03	(0.04)	0.60

[a]All models are adjusted for time of day (am/pm).

SE indicates standard error; PEF, peak expiratory flow; FEV_1, forced expiratory volume in the first second; PM, particulate matter.